Today: how user interfaces connect with cognitive strengths

- Mental models
- Gulfs of evaluation and execution
- Direct manipulation
- Externalized cognition
Mental models
Consider this refrigerator...

problem:
freezer too cold, but fresh food just right

Concept from: Don Norman, The Design of Everyday Things.
The refrigerator has two dials

How does the system work?

<table>
<thead>
<tr>
<th>Setting</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Setting</td>
<td></td>
<td></td>
<td>C</td>
<td>4</td>
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<tr>
<td>Colder Fresh Food</td>
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<td>C</td>
<td>5-6</td>
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<tr>
<td>Coldest Fresh Food</td>
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<td>B</td>
<td>7</td>
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<tr>
<td>Colder Freezer</td>
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<td>D</td>
<td>6-7</td>
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<tr>
<td>Warmer Fresh Food</td>
<td></td>
<td>C</td>
<td>3-1</td>
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<tr>
<td>OFF (both)</td>
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<td>OFF (both) 0</td>
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</tbody>
</table>

- C and 4
- C and 5-6
- B and 7
- D and 6-7
- C and 3-1
- OFF (both) 0
A likely model...

i.e., independent controls

freezer

Cooling unit

fridge

Cooling unit
Actual model
Now can you fix the problem?

freezer

fridge

Ratio

Cooling unit

A B C D E

7 6 5 4 3
Mental model

• User’s thought process about how something works in the real world
• Correct mental model: one dial controls the cooling unit, the other controls the ratio of cold air to fridge and freezer
• Incorrect mental model: two separate cooling units
Goal of design: instill the correct mental model

- If users have the correct understanding of a design, they can confidently take action
- Users develop their model through interaction with the system
- Designers begin with the correct mental model
- Often, the user’s model $\neq$ the designer’s model
Conceptual Model Mismatch

• Mismatch between designer’s & user’s conceptual models leads to...
  • Slow performance
  • Errors
  • Frustration
  • ...

Mental models arise from experience, metaphor, and analogical reasoning

• “A text processor is a typewriter”
• We have models (beliefs) about our own behavior, of others, of objects, software...
• Our models are incomplete, inconsistent, unstable in time, and often rife with superstition

Slips

• Correct model but accidental execution

  • e.g., trying to hit the save button but accidentally quitting
  • e.g., accidentally shifting the car into Neutral

Mistakes

• Incorrect model

  • e.g., looking for a save button in Google Docs
  • e.g., not using the clutch in a manual transmission car
Clear mapping between control + function

Clear mapping between control + function
Example (good)

Mercedes S500 Car Seat Controller
Gulfs of execution and evaluation
How might we improve the measuring cup?
The Gulf of Execution: How do you do?
The Gulf of Execution: How do you *do*?

- How do I add more water to the measuring cup?
- How do I remove water?
The Gulf of Evaluation: How do you know?
The Gulf of Evaluation: How do you know?

• How much water is in the measuring cup now?
The making of gulfs. How easily can someone:

- Determine the function of the device?
- Tell what actions are possible?
- Determine mapping from intention to physical movement?
- Perform the action?
- Tell what state the system is in? / if it’s in desired state?
- Determine mapping from system state to interpretation

Questions from Don Norman, *The Design of Everyday Things*
To reduce the gulfs, provide...

- Visibility (perceived affordances or signifiers)
- Feedback
- Consistency (also known as standards)
- Non-destructive operations (hence the importance of undo)
- Discoverability: All operations can be discovered by systematic exploration of menus
- Reliability. Operations should work. Period. And events should not happen randomly.

Source: Donald A. Norman and Jakob Nielsen, ACM Interactions, 2010
Direct manipulation
Act directly on the object of interest

indirect:
Act directly on the object of interest

direct:
Direct manipulation

• Immediate feedback on actions
• Continuous representations of objects
• Leverage metaphor
COMMAND LINE v. GUI
<table>
<thead>
<tr>
<th>Principle</th>
<th>Command Line</th>
<th>GUI</th>
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</thead>
<tbody>
<tr>
<td>Visibility</td>
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<td>Feedback</td>
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<td>Consistency</td>
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<td>Non-destructive</td>
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<td>Discoverability</td>
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<td>Reliability</td>
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</table>
Successful Indirection?
courtesy of Takeo Igarashi
“If technology is to provide an advantage, the correspondence to the real world must break down at some point.”

- Jonathan Grudin
CURRENT PRACTICE

NEW TECHNOLOGY

minimize this distance
Final Scratch
Externalizing cognition
We need two volunteers. One stays, one goes outside.
Let’s play number scrabble

- Two players
- Numbers available: 1, 2, 3, 4, 5, 6, 7, 8, 9
- Players draw alternately, without replacement
- Win if three of your numbers add up to 15
Let’s play number scrabble

- X takes 8
- O takes 2
- X takes 4
- O takes 3
- X takes 5

What should O do?
OK, go outside. Don’t talk to your partner. We’ll get them in a second.
We’ll encode this game visually

<table>
<thead>
<tr>
<th>4</th>
<th>9</th>
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<tbody>
<tr>
<td>3</td>
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<td>7</td>
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<tr>
<td>8</td>
<td>1</td>
<td>6</td>
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</tbody>
</table>
Let’s go get Player Two.
Tic-Tac-Toe: You are Player O.
The Color Puzzle

goal Put all the colors in one bin

rule 1 Only one color can be transferred at a time

rule 2 Colors can only be moved if certain properties hold:

- can only be put in an empty bin
- can be put in empty bins or bins with
- can be put in empty or
- can be put in empty or
- can be put in empty or
The Towers of Hanoi Puzzle

goal Put all the rings on one peg

rule 1 Only one ring can be transferred at a time

rule 2 A ring can only be transferred to a peg on which it will be the smallest

rule 3 Only the smallest ring on a peg can be transferred to another peg
### Anscombe's Quartet

<table>
<thead>
<tr>
<th>Set A</th>
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<th>Set B</th>
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<th>Set C</th>
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#### Summary Statistics

- Linear Regression: \( Y = 3 + 0.5X \)
- \( R^2 = 0.67 \)
- \( u_x = 9.0 \quad \sigma_x = 3.117 \)
- \( u_y = 7.5 \quad \sigma_y = 2.03 \)

[Anscombe 73]

courtesy of Jeff Heer
The ability to take data—to be able to understand it, to process it, to extract value from it, to visualize it, to communicate it—that's going to be a hugely important skill in the next decades, … because now we really do have essentially free and ubiquitous data. So the complimentary scarce factor is the ability to understand that data and extract value from it.

Hal Varian, Google's Chief Economist
The McKinsey Quarterly, Jan 2009

What is visualization?
“Transformation of the symbolic into the geometric” [McCormick et al. 1987]
“... finding the artificial memory that best supports our natural means of perception.” [Bertin 1967]
“The use of computer-generated, interactive, visual representations of data to amplify cognition.” [Card, Mackinlay, & Shneiderman 1999]

Set A

Set B

Set C

Set D

courtesy of Jeff Heer

[Anscombe 73]
Problem Solving as Representation

“Solving a problem simply means representing it so as to make the solution transparent”

—Herbert Simon, The Sciences of the Artificial
Naturalness Principle

• Experiential cognition is aided when the properties of the *representation* match the properties of the *thing* being represented

source: Don Norman, Things that Make Us Smart
Offloading Working Memory
e.g., Getting Things Done
Proteus Ingestable Networked Pill

- Sensor and transmitter encapsulates pill
- Stomach acid is part of battery
- Transmits pill
  --> patch
  --> iPhone
  --> Internet

Images courtesy of Proteus Biomedical
Offloading Computation
Actual model
Now can you fix the problem?
When interfaces help people distribute cognition, it can...

- Encourage experimentation
- Scaffold learning and reduce errors through redundancy
- Show (only) differences that matter
- Convert slow calculation into fast perception
- Support chunking, especially by experts
- Increase efficiency
- Facilitate collaboration
external feedback: cheap experimentation
London Underground
Color: Edward Tufte
Color: Edward Tufte
Chase and Simon, 1973:
Experts learn to “chunk” visual stimuli
Chase and Simon, 1973:
Experts learn to “chunk” visual stimuli

<table>
<thead>
<tr>
<th></th>
<th>Experts</th>
<th>Novices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual game</td>
<td>90%</td>
<td>25%</td>
</tr>
<tr>
<td>Random game</td>
<td>25%</td>
<td>25%</td>
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</table>
Chunking in Interfaces

Ideally, we want a one-to-one mapping between concepts and gestures. User interfaces should be designed with a clear objective of the mental model we are trying to establish. Phrasing can reinforce the chunks or structure of the model.
How a Cockpit Remembers its Speed

Ed Hutchins
Worth 10,000 Words?

Jill H. Larkin, Herbert A. Simon, Why a Diagram is (Sometimes) Worth Ten Thousand Words
Informational Equivalence
Informational Equivalence

!=

Computational Equivalence